

HVAC Interoperability



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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Program's final report and its attachments are intended to provide a complete record of the objectives, methods, findings and accomplishments of the High Performance Commercial Building Systems (HPCBS) Program. This Commercial Building Energy Benchmarking attachment provides supplemental information to the final report (Commission publication # 500-03-097-A2). The reports, and particularly the attachments, are highly applicable to architects, designers, contractors, building owners and operators, manufacturers, researchers, and the energy efficiency community.

This document is the fourth of 22 technical attachments to the final report, and consists of software and a research report:

- IFC HVAC (E2P2.3T1d)
- Improving Building Energy Performance Simulation with Software Interoperability (E2P2.3T3b)

The Buildings Program Area within the Public Interest Energy Research (PIER) Program produced this document as part of a multi-project programmatic contract (#400-99-012). The Buildings Program includes new and existing buildings in both the residential and the nonresidential sectors. The program seeks to decrease building energy use through research that will develop or improve energy-efficient technologies, strategies, tools, and building performance evaluation methods.

For the final report, other attachments or reports produced within this contract, or to obtain more information on the PIER Program, please visit <http://www.energy.ca.gov/pier/buildings> or contact the Commission's Publications Unit at 916-654-5200. The reports and attachments are also available at the HPCBS website: <http://buildings.lbl.gov/hpcbs/>.

Abstracts

EXPRESS Code of the IFC2x2 Integrated Data Model of Buildings

This project has extended the Industrial Foundation Classes (IFC) schemata to support the modeling of heating, ventilation, and air conditioning components and systems in various IFC-compatible building energy performance simulation and HVAC design tools (such as EnergyPlus and HAP), as well as HVAC manufacturers. The extended HVAC schemata were integrated into the latest release of the IFC data model. These extension schemata provide developers of HVAC related software with rules and regulations to unambiguously and uniquely define HVAC equipment, components and systems. This allows software end users (i.e. users of software that implemented the IFC data model of buildings and its HVAC extensions schemata) to seamlessly exchange data with other compatible software.

The extension schemata are defined in EXPRESS file format in file
http://iaiweb.lbl.gov/bs8/documents/BS-8_Model/html.zip

Improving Building Energy Performance Simulation With Software Interoperability

Interoperable software makes it possible to seamlessly exchange data among different compliant applications. Seamless data exchange substantially saves time and resources that makes the use of energy software feasible in industry projects where it normally is not used. Software interoperability offers another important benefit: opportunity to increase the quality of building energy simulation through simultaneous interaction of multiple design and simulation tools that is possible because of direct data exchange among them.

This paper discusses the new IFC HVAC extension schemata that are included in the latest release of the IFC data model (IFC2x2). It describes the new model functionalities and lists the many industry processes now supported by the IFC data model. The paper also describes an example of interoperable software *environment* in which data are exchanged among a CAD tool, a duct sizing and layout tool, and EnergyPlus that result in a more representative simulation of a building's energy performance significantly sooner than is normally attainable. Data exchange in this example is based on the IFC2x version of the data model of buildings from the International Alliance for Interoperability (IAI). In addition, the paper also discusses the possible gains from interoperable simulation of building energy performance, as well as some of the current issues in data exchange for such simulation.

HPCBS

High Performance Commercial Building Systems

Improving Building Energy Performance Simulation with Software Interoperability

Element 2 Life-Cycle Tools
Project 2.3 Interoperability

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IMPROVING BUILDING ENERGY PERFORMANCE SIMULATION WITH SOFTWARE INTEROPERABILITY

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ABSTRACT

Interoperable software makes it possible to seamlessly exchange data among different compliant applications. Seamless data exchange substantially saves time and resources that makes the use of energy software feasible in industry projects where it normally is not used. Software interoperability offers *another important benefit*: opportunity to increase the *quality* of building energy simulation through simultaneous interaction of multiple design and simulation tools that is possible because of direct data exchange among them.

This paper discusses the new IFC HVAC extension schemata that are included in the latest release of the IFC data model (IFC2x2). It describes the new model functionalities and lists the many industry processes now supported by the IFC data model.

The paper also describes an example of interoperable software *environment* in which data are exchanged among a CAD tool, a duct sizing and layout tool, and EnergyPlus that result in a more representative simulation of a building's energy performance significantly sooner than is normally attainable. Data exchange in this example is based on the IFC2x version of the data model of buildings from the International Alliance for Interoperability (IAI). In addition, the paper also discusses the possible gains from interoperable simulation of building energy performance, as well as some of the current issues in data exchange for such simulation.

INTRODUCTION

Industry Foundation Classes (IFC), developed by the International Alliance for Interoperability (IAI) [IAI 1995], are gaining acceptance as the only *non-proprietary* intelligent, comprehensive and universal data model of buildings. After years of development, the model is finally offering functionality that can facilitate software interoperability in support of work processes for a significant part of a building's life cycle, as was amply demonstrated at the IAI Industry Day in Washington, DC on May 14, 2003.

The data model has become quite large and complex. It now contains a "frozen" part that will not change for at least three years, and a part that contains model extensions and that can continuously be added to. A model configuration that is "frozen" at some point in time and development constitutes a "platform." It provides model stability needed in software development. Software developers no longer have to make adjustments to their software with each new model release or update. The current "platform" version of the IFC model "freezes" resource, kernel, and product, process and modeling aid extension schemata as defined in the IFC2x version of the model. This "platform" became an ISO PAS standard in November 2002 (ISO/PAS 16739).

Serious implementation of the IFC data model in industry software started after the release of IFC 1.5.1 early in 1998. That version had one primary functionality: to support the exchange of building geometry data. The next version, IFC 2.0 in early 1999, included *rudimentary* definitions needed to support *some* of the data exchanges with non-CAD applications, such as cost estimating applications. IFC2x, released in October 2000, included some adjustments to building geometry as well as additional industry domain definitions.

For quite a while, most implementers of IFC were CAD software developers or developers of products that employed CAD engines. Their applications could exchange building geometry data but virtually no "downstream" data needed by applications that support work flow and processes "after CAD." BLIS consortium (Building Lifecycle Interoperable Software) was formed with the release of the IFC 2.0 model to provide software interoperability *throughout* a building's life cycle [BLIS 2000]. While BLIS accomplishments to date are remarkable, data exchange was still limited to types defined in that version of the model.

The latest IFC model release, IFC2x2, includes model extensions that specifically support interoperability for "post-CAD" applications. It includes substantial model enhancements for three major industry domains – HVAC, electrical, and

structural – as well as enhancements to modeling of building architecture, facilities management, and more. In addition, it includes time series, a model functionality that is critical to any analysis application [IAI-MSG 2003].

For the first time it is now possible to write IFC interfaces to electrical and structural analysis applications. This will, for the first time, bring to these industry disciplines software interoperability that is based on an open data model. HVAC model extensions make it now possible to write interfaces to HVAC design and simulation tools, as well as other types of applications (such as cost estimating) that employ HVAC definitions. In addition to importing building geometry data directly from CAD, this enables the exchange of HVAC data with other tools used in the work process.

IFC HVAC EXTENSION SCHEMATA

IFC HVAC extension schemata were developed at the Lawrence Berkeley National Laboratory (LBNL) in collaboration with 13 organizations and with government and private sector funding from eight countries. The project is part of the IAI project structure; thus its name “BS-8,” which stands for Building Services project number 8 [BS-8 2001].

The main objective of BS-8 was to extend the IFC data model with schemata needed to *fully* support the *modeling and simulation* of HVAC components and systems. The pragmatic goal was to *enable rich data exchange* among the various building simulation tools in use today and in the future.

Data can be imported from upstream and/or exported to downstream applications in IFC or (by some of the tools) in XML format. Besides previously defined data types that depict building geometry, data types defined and enabled in BS-8 include

- General and performance specifications of materials
- General specifications of HVAC and other simulation related equipment, systems and furnishings
- Performance specifications for the above.

Downstream applications targeted for reception of exchanged data include

- Other HVAC (design) applications
- Other building energy performance simulation tools (such as air-flow models)
- Cost estimating applications
- Commissioning tools
- Building operations and maintenance software

- Code-checking applications
- Software that serves utility companies
- Many other types of applications that use HVAC definitions.

Specifically, the IFC HVAC extension schemata directly support the *building energy performance simulation* processes. Implicitly, they support

- Dynamic load estimation
- HVAC design
- HVAC equipment selection
- Measurement and verification (HVAC view)
- Building performance metrics (HVAC view)
- HVAC system and equipment commissioning
- HVAC system and equipment retrofit
- HVAC system and equipment physical layout
- HVAC system and equipment product data (catalogues, external data bases).

Processes that are *partially* supported by IFC HVAC extensions include

- Energy code compliance
- Interference checking
- Cost estimating
- HVAC construction documents
- Construction and installation
- Procurement
- Maintenance
- Operations
- Fault detection and diagnostics
- Emergency response
- Accessibility
- Utility billing and cost allocation

The new IFC HVAC extensions integrated HVAC schemata that were developed by the BS-7 project. That project, done at VTT in Finland, concentrated mainly on the definition of heating equipment and systems [Lappalainen et al. 2000].

It is important to note that the modeling of building controls in the new extension schemata is still only at a fairly rudimentary level. Forging agreement among the various controls equipment manufacturers proved to be too difficult a task; this remains a major task for the future. Controls definitions in the IFC HVAC extension schemata are now limited to what is needed

to support simulation with current tools, such as EnergyPlus.

BS-8 also added the ability to properly model two important general modeling features: connectivity and time series. The IFC connectivity schema was extended to include any type of connecting HVAC equipment and parts. Time series, a completely new schema at resource level, enables the modeling of data that are defined dynamically and change in time. This is a critical functionality for any performance analysis tool, including all dynamic building simulation tools.

If implemented, software applications that are compatible with IFC versions prior to IFC2x2 can exchange only *rudimentary* HVAC data. The new, extended model of HVAC components makes it possible for software to exchange data that *completely* define HVAC equipment and systems (to the extent such definitions are needed and used). *This model defines and documents the rules and protocols by which all HVAC hardware components in a building and their performance are uniquely and unambiguously depicted in all software that follows these rules and protocols.* It provides a common basis for interested software developers to agree how to define and exchange HVAC data and gives them, for the first time, a common and widely accepted data structure.

IMPACT ON ENERGY SIMULATION

With interoperable software users can, in general, very much expedite their work on industry process tasks. They can not only dramatically reduce the effort and resources needed in preparation of input, but can also eliminate duplication and repetition of data; they can dramatically reduce error in data entry that results in the need for “fixes” later, minimize misunderstandings, and reduce risk and liability in decision making [Bazjanac and Crawley 1999; Bazjanac 2001]. All these benefits are now also available to software that implements the IFC HVAC extension schemata.

In addition, the new HVAC model extensions make it possible to link the use of HVAC design and simulation tools at the same time, and thus improve the *quality* of building energy performance simulation. Most energy performance simulation tools, such as EnergyPlus, rely on some assumptions that are built-in in the tool or in the data set used in a particular simulation. When such assumptions can be replaced by better data generated with other tools and promptly imported into simulation *when needed*, the quality of the resulting simulation can be significantly improved.

A demonstration of such improved quality of energy performance simulation, prepared for government

agencies that funded the BS-8 project, showed how much can be gained by importing actual design data generated by a duct design application directly into EnergyPlus. The demonstrated gain was based on bi-directional data exchange attainable during a two hour meeting because the software involved was interoperable [Bazjanac 2003].

ENERGYPLUS-MAGICAD DEMO

EnergyPlus currently does not support data that define in detail a duct design specific to the building that is being simulated, nor the duct system’s performance. It uses data that define ducts and their performance only in a generic way. Duct design tools, such as MagiCAD [Progman 2003], typically do not have the ability to perform full-scale annual energy analysis. The aforementioned demonstration showed the process of importing specific duct performance data, generated by a duct design tool (MagiCAD) directly into annual energy performance simulation (by EnergyPlus).

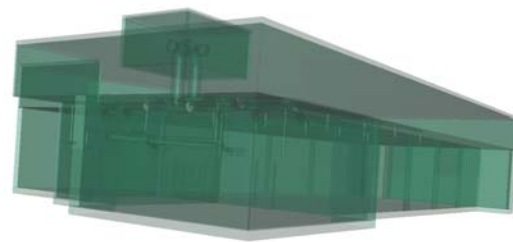


Figure 1 – Small bank building

Figure 1 shows a “see-through” view of the building that was used as subject of the simulation. It is a small, 365m² (3,900 sq.ft.) one story bank branch building, located in San Diego, CA for the simulation. The banking floor, the vault and bathrooms are conditioned; the lobby is not. The building has a plenum, and a small mechanical room on the roof. It is oriented straight north; shading overhangs (part of the plenum/roof) pose non-trivial modeling issues, as parts of the same bottom surface construction are inside conditioned areas while other parts are outside the building. The lobby and the banking floor are fully daylight. The building is served by a single duct variable volume (VAV) system with reheat.

As shown in Figure 2, the demonstration started by importing building geometry from a CAD file into EnergyPlus. The 3-D building model was defined in ArchiCAD and saved in IFC format; the resulting file was imported into BS Pro COM Server [Karola et al. 2002], a middleware that simplifies complex geometry definitions into simpler form as needed by non-CAD tools. In this case, building geometry was then imported into EnergyPlus via its BS Pro Client

and in the form needed specifically by EnergyPlus. The HVAC system for the building was designed externally and its EnergyPlus definition was entered manually, as were other data needed for a meaningful simulation (such as occupancy and use schedules). The system was sized using EnergyPlus design-day simulation; results from the corresponding annual simulation were kept for later comparisons.

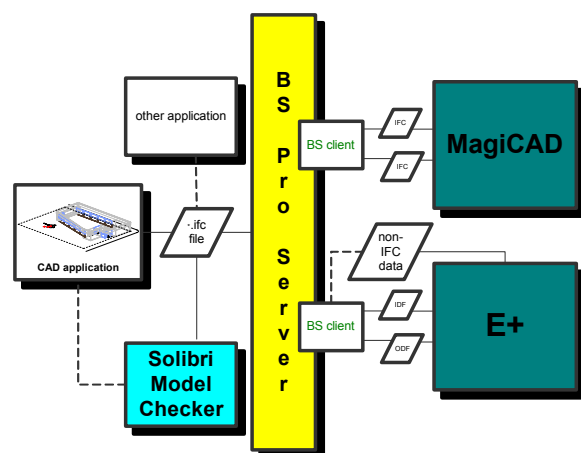


Figure 2 –Data paths in the exchange among CAD and “downstream” applications facilitated by BS Pro Server middleware

Zonal air-flow data, generated in EnergyPlus design-day simulation, were then exported directly to MagiCAD via BS Pro Clients for EnergyPlus and for MagiCAD. Based on a pre-designed conceptual duct design for the building, MagiCAD checked air-flow rates in devices, sized and balanced ducts (both supply and exhaust), and returned the results of calculation - drop in duct pressure - back to EnergyPlus, again via BS Pro Clients for MagiCAD and for EnergyPlus. The process was completed with a new EnergyPlus annual simulation that included imported duct pressure data.

	with Energy Plus assumptions about duct pressure	with MagiCAD calculations of duct pressure
Simulated annual energy consumption (J)	107023768667	102664514342

Figure 3 – Comparison of small bank’s annual energy consumption with different duct performance data

The comparison of the annual energy consumption from simulation with EnergyPlus before and after data exchange with MagiCAD shows a difference of approximately 4% (Figure 3). This represents quite a significant improvement in the quality of results of

simulation, considering that data defining duct pressure are only a small part of a data set used in simulation that can be generated more accurately by other tools.

It is remarkable that increase in quality of simulation can now be attained in a fraction of time that was previously needed if such improvements were sought. Indeed, a small multidisciplinary team of competent professionals can enable multi-directional exchange of data among different applications in very little time; data in support of a decision can now be generated in the same meeting in which questions were posed. (The complete demonstration described above – including the detailed explanation of what was being observed – took less than 70 minutes.)

AN OPPORTUNITY FOR SOFTWARE DEVELOPERS

With the IFC2x2 data model available, developers of software that in some way includes definitions of HVAC equipment and systems have an opportunity to make their software interoperable with other tools that use and/or generate HVAC related data. This will require the writing of interfaces that map the IFC data structure to their software’s own data structure, and vice versa.

LBNL started an “IFC HVAC implementers’ round table” in December 2002 to facilitate such IFC implementation. Members of the “round table” meet and communicate regularly to define their own “views” of the IFC model, forge “implementers’ agreements,” and help each other resolve model and coding issues. The forging of exchange views and implementers’ agreements is critical, as they define which HVAC and other IFC definitions will be implemented by all implementers participating in an exchange scenario, how these will implemented, and which will not be implemented at all.

The IFC data model contains more definitions in more detail that any single software application can possibly implement. Most “downstream” tools need only selected definitions, and often need definitions in less detailed form than defined by the originating application. Extracting and transforming such data on their own may prove too costly and difficult for many “downstream” applications. This provides a market for middleware – software that will extract specific data from the IFC project data base, manipulate them, and deliver them to a tool or tools in form that makes them usable without further transformation.

One should remember that end users will repeatedly use a specific software tool *only if it helps them*: if they can identify that it helps them solve problems, expedite tasks and their work, prevent errors and help them communicate a (more) professional image. In

other words, end users have little tolerance for tools that do not work as expected, cannot deal with problems end users expect them to, are not mature and/or robust, or still have bugs [Bazjanac 2002]. This also applies to interfaces, such as interfaces to the IFC data model.

It is also important to note that architects' definitions of buildings in CAD do not necessarily reflect the needs of energy simulation. An energy simulation view of a building typically requires thermal zoning, which often requires agglomeration and/or division of "rooms" or "spaces" defined by architects. The redefinition of the building model to reflect thermal zoning often requires the reuse of a (3-D) CAD tool, an act that may be beyond the typical simulation user, especially if the user is not at ease in manipulating 3-D building information models (BIMs). This presents an opportunity for software developers to create "front end" (graphic) user interfaces that can do this task on top of imported original building geometry in a user friendly, easy-to-use manner. To be widely useable, it is needless to say that such user interfaces will have to be interoperable and not dedicated (and limited) to a single CAD tool and its file format.

DATA EXCHANGE ENVIRONMENTS

Exchange of data among interoperable software applications thus far has been based on file exchange. Project models are saved in their entirety as IFC files, which are identical to ISO/STEP Part 21 exchange files [ISO 1994]. As the IFC model becomes larger and more complex, IFC project models' size approaches limits of manageability even for modestly sized buildings. This may be even more critical for files saved in XML format. In addition, physical file based exchange prevents *partial model exchange* (or, at the least, makes it very difficult), which may be the only way to deal with enormously large project models of the future.

IFC model servers are already beginning to emerge. Such servers are enabling partial model exchange: They host project models that are accessible remotely via web services. Remote software applications can browse project models, find and extract definitions they need, modify and/or append them, and return them to the model server. Several programmer tools vendors are now offering server software and tools in support of IFC model servers.

CONCLUSIONS

The IFC data model of buildings has reached a maturity that makes it increasingly beneficial to developers of "downstream" applications that support industry processes during a building's life cycle to implement the model in their software. Developers of HVAC software can benefit immediately from the

new data model of HVAC components. They can now write interfaces to their software that will enable data exchange with other software applications that need or provide such data and have an IFC interface themselves. This provides vendors of such tools with the software functionality long sought by industry software users.

The greatest benefits are ultimately coming to HVAC software end users. Users of applications that are "downstream" will be able to import data directly from "upstream" applications that generated them. With *minimal effort* they will be able to:

- Import equipment data and performance specifications
- Make comparisons based on performance or cost
- Design and specify systems in more detail than before
- Simulate performance with data of highest quality and fidelity
- Engage in "what-if" analysis
- Seamlessly export data they generate themselves

The new IFC2x2 data model provides a unique opportunity for developers of HVAC software to interface to stable and internationally agreed upon ways to describe what their software is dealing with. It provides equipment manufacturers with an opportunity to describe their products in a way and format that software tools will be able to import directly, enabling the end user to select products for their merit. The data model is ready for implementation: The more and the sooner software developers and equipment manufacturers embrace this data model, the sooner they will give the industry end user what has been badly missing – HVAC software interoperability – and the sooner they will be able to reap the benefits from it.

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REFERENCES

Bazjanac, V., and D.B. Crawley. 1999. Industry Foundation Classes and Interoperable Commercial Software in Support of Design of Energy-Efficient Buildings. In *Proceedings of Building Simulation '99*, Kyoto.

Bazjanac, V. 2001. Acquisition of Building Geometry in the Simulation of Energy Performance. In R. Lamberts et al. (eds), *Building Simulation 2001, Proc. intern. conf., Rio de Janeiro*, Vol. 1: 305-311. ISBN 85-901939-2-6.

Bazjanac, V. 2002. Early Lessons From Deployment of IFC Compatible Software. In Z. Turk and R. Scherer (eds), *eWork and eBusiness in Architecture, Engineering and Construction, Proc. fourth Euro. conf. product process modelling, Portoroz, SLO*: 9-16. Balkema. ISBN 90 5809 507 X.

Bazjanac, V. 2003. Element 2, Task 3 in Selkowitz, S.E., *High Performance Commercial Building Systems, Final Report*, LBNL.

Building Lifecycle Interoperable Software (BLIS). 2000. <http://www.blis-project.org>.

Building Services Project Number 8 (BS-8). 2001. <http://eetd.lbl.gov/btd/iai/bs8/index.html>

ISO. 1994. *ISO-10303-Part 21*, ISO-10303-1:1994.

Karola, A., H. Lahtela, R. Hänninen, R.J. Hitchcock, Q. Chen, S. Dajka and K. Hagström. 2002. BSPro COM-Server - Interoperability between software tools using industry foundation classes. In *Energy and Buildings*, No. 34: 901-907.

International Alliance for Interoperability (IAI). 1995. <http://www.iai-international.org>.

Lappalainen, V., S. Karjalainen, T. Salisbury and D. Sucic. 2000. *HVAC Performance Validation: Process definitions, Information requirements Analysis and Object Type Definition*, IFC R3.0 Domain Project Documentation, VTT.

Progman OY. 2003. MagiCAD. <http://www.progman.fi/english/emagicad.htm>